J. stored Prod. Res. 1977, Vol. 13, pp. 23–28. Pergamon Press. Printed in Great Britain.

ULTRASOUND AS A DETERRENT TO *RATTUS NORVEGICUS*

G. KEITH LAVOIE and J. F. GLAHN

Denver Wildlife Research Center, Denver, Colorado 80225, U.S.A.

(*First received* 2 *March* 1976)

Abstract—Acoustical outputs were determined for five ultrasonic generators, claimed by the manufacturers to be effective in driving rodents from buildings; wide variation of frequencies, amplitudes, duty cycles, and pulse rates were found. Two contrasting types of generators were selected for field testing. One produces a wide band of frequencies, peaking at 41 kHz, but with other frequencies at varying amplitudes and pulse rates and giving a continuous output approaching white noise. The other produces a narrow frequency band, at approximately 22 kHz, approaching a pure tone; it gives intermittent signals, of the highest amplitude of those tested. During the field testing *Rattus norvegicus* feeding activity was monitored and compared with the generators in an off–on sequence for 3-week periods in a room with the generators and an adjacent nonsound room. The wide band generator produced no measurable decrease in activity in the sound room; however, food consumption increased in the nonsound room. The narrow-band generator initially decreased rat feeding activity in the sound room and increased food consumption in the nonsound room. However, after 1 week, feeding activity increased again in the sound room, indicating habituation to the sound. It appears the aversive properties of these devices are not sufficient to keep rats from food.

INTRODUCTION

ALTHOUGH numerous devices for expelling rodents from buildings by means of high-frequency sound (15 to 19 kHz) and ultrasound (greater than 19 kHz) have been produced and marketed in the United States since about 1960, quantitative evidence on the effectiveness of these devices, particularly under warehouse conditions, is lacking.

GOUREVITCH and HACK (1966) measured the auditory thresholds in albino rats between 10–50 kHz. They found the greatest sensitivity to be 1 octave wide and located in the vicinity of 40 kHz. They further extrapolated that the upper auditory limit is in the octave between 50–100 kHz. However, most research to date indicates that sound and ultrasound at less than damaging intensities is usually only mildly aversive to albino rats, wild Norway rats, and house mice, *Mus musculus* (CAMPBELL and BLOOM, 1965; SPROCK *et al.*, 1967; GREAVES and ROWE, 1969; MARSH *et al.*, 1962; BURGER, 1967).

In contrast, the findings of KENT and GROSSMAN (1968); BELLUZZI and GROSSMAN (1969); and in part, SPROCK *et al.* (1967); and MYERS (1967) indicated that the sounds with frequencies spanning 1/2 octave or greater were more than mildly aversive to wild Norway and albino rats.

The research described here was a determination of the acoustic outputs of five commercially available ultrasonic generators which, by the manufacturer's claims, were sufficiently noxious to wild rats to drive them from buildings. Our objective was to find a generator with an output covering 1/2 octave or more and preferably with primary frequencies spanning 40 kHz, then to evaluate this device under warehouse conditions to determine its aversive effect on wild Norway rats. For comparison a second device having a narrow frequency output at less than 40 kHz was also tested under similar conditions.

MATERIALS AND METHODS

Selection of devices for field testing

Five types of commercially available ultrasonic generators were analyzed in this study. Four units of each type were tested, except for generators D and E of which only three and two units, respectively, were evaluated. Each unit was tested in a sound

EXHIBIT C-5

chamber with the generator 0.914 m from a B&K¶ 6.3 mm free field condenser microphone type 4135 with a flat frequency response from 200 Hz to greater than 50 kHz. The signal was received from all generators (except E) by a B&K impulse precision sound level meter, type 2209, with a frequency range of 10 Hz to 70 kHz, and with a B&K octave filter set, type 1613. The receiving equipment for generator E consisted of a preamplifier, a 20 kHz band-pass filter, and a Hewlett–Packard Model 400 H voltmeter calibrated by Engineering Dynamics, Inc. The output from each generator was analyzed with a Hewlett–Packard 302A wave analyzer equipped with an AC 297 sweep drive. Frequencies were swept from 16 to 50 kHz and a reading taken at 1 kHz increments. Oscilloscope analysis was made on one unit of each type to check the results of the wave analyzer and to estimate the pulse rate and duty cycle. Table 1 summarizes the results of these analyses.

Generator A produces a signal electronically through a crystal transducer. Devices B and D are pneumatic generators producing sound by forcing compressed air through a transducer. Generator type E, another electronic device, employs three transducers producing similar output frequencies. This generator had the highest average decibel level and the narrowest frequency output of any of the five types tested. In contrast to the other four types, device C produces a signal through a crystal and is quite different in signal properties. Although the lowest in overall decibel level, it produced a frequency range over one octave with a peak amplitude at 41 kHz. The wave analyzer and oscilloscope showed a wide band of noise produced by different frequencies at varying amplitudes and pulse rates with a continuous output of sound approaching white noise. From these tests we selected types C and E for warehouse testing.

Methods

An unoccupied packing house currently used as a warehouse was selected as a test site. This building had a long history of rat infestation up to 1971, when the building was unoccupied. The building showed abundant rat harborage, but only minimal rat activity due to the lack of food. Food was placed in two adjoining rooms in the basement in an attempt to attract rats from the large population in an adjacent hog market. Little, if any, increased activity was noted after several weeks of observation. Therefore, we introduced 20 Norway rats into the two rooms; burrowing was apparent in a dirt bottomed elevator shaft 4 weeks after the introduction, and the removal of food indicated that they had become established in the two rooms. At the conclusion of testing, we estimated that 25–30 rats occupied the two rooms.

A 1.5 by 1.5 m grid system was set up on the floor of the primary study room (Fig. 1). We established 64 feeding spots, (15 by 15 cm floor tiles), one at each point of the grid. Activity was determined by placing 10 g of ground laboratory ration and

TABLE 1. SIGNAL PROPERTIES OF FIVE COMMERCIALLY AVAILABLE ULTRASONIC GENERATORS FOR RODENT CONTROL

Generator	N	DB level* 21–42 kHz (avg.)	Frequency range† Fundamental (kHz)	Frequency range† Harmonic (kHz)	Amplitude peak Fundamental (kHz)	Amplitude peak Harmonic (kHz)	Pulse rate pulse/sec.	Duty cycle‡
A	4	90.75	22–24	46–46	23.0	46	66	1/10
B§	4	103.0	19–26	41–48	21.5	45	29	1/2
C	4	87.0	19–50	None	41.0	None	N/A	1/1
D§	3	93.7	20–24	43–45	22.0	44	33	1/2
E	2	111.5	21.5–22.5	41.5–44.5	21.5	43	0.17	2/3

* Reference = 0.002 microbars RMS.
† Based on reading >1% of the power for each generator.
‡ Duty cycle is the fraction of time signal pulse is on.
§ Testing of all generators was at approximately 5000 feet above sea level, resulting in slightly reduced compressor efficiency of the two pneumatic generator types.

¶ References to trade names does not imply endorsement of commercial products by the U.S. Government.

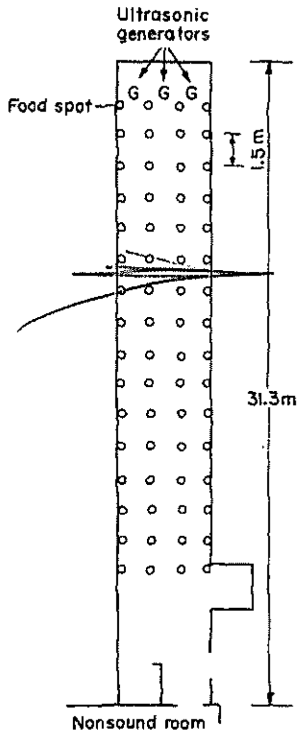

FIG. 1. Room dimensions, food spot positions, and generator location(s) within the sound room.

flour on each of the floor tiles and examining them every 4th day for removal of food. The flour and laboratory ration (a preferred food) was then replaced on those tiles showing feeding activity. Four feeding stations, each containing 100 g of oat groats (a less preferred food), were established in the adjacent nonsound room. The weight of oat groats consumed was determined every 4th day and the grain replenished.

For the first test, three type C generators were installed 30 cm above the floor, at the points shown in Fig. 1, and directed along the length of the room (rats could enter only at the opposite end). Rat activity was monitored during two 3-week periods. During the first period (generators off), normal baseline activity was determined. During the second period, the generators were turned on, producing a sound gradient along the length of the room. Sound level readings were taken at each food spot and at the feeding stations in the nonsound room.

The test site and design used to evaluate generator type E was the same as with type C generators with two exceptions. First, we replicated the test, that is, it consisted of two alternating 3-week sound-off and 3-week sound-on periods. Second, only one generator was used and was placed in the middle position shown in Fig. 1.

RESULTS

Type C generator

The sound gradient produced by type C generators, calculated as the average decibel level at each row of four food spots, is shown in Fig. 2. The sound attenuated from an average of 89 db at the row closest to the generators to an average of 59 db at the last row, 22.5 m from the generators. In the nonsound room sound level readings of <50 db (the lowest sensitivity of our equipment) were recorded at each of the four feeding stations.

In the sound room all 64 food spots showed rat activity at each of the 5 inspections during the sound-off period and again during the sound-on period. Grain consumption

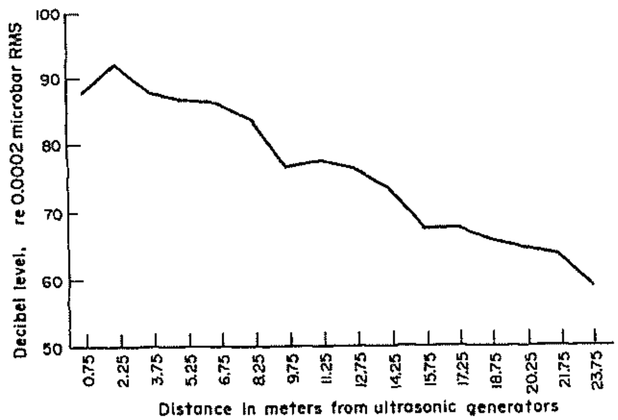

FIG. 2. Sound gradient produced by three type C generators over the food spot area.

in the nonsound room averaged 174 g per inspection with the sound off and 255 g per inspection with the sound on, a 47% increase. A *t*-test showed that this increased consumption was significant ($p \leq 0.05$).

Type E generator

The sound gradient produced by generator E is shown in Fig. 3. The sound attenuated from an average of 94 db at the row of food spots closest to the generator to an average of 77 db at the row furthest from the generator. In the nonsound room amplitude levels were <50 db at each of the four feeding stations.

In the first replication, of two 3-week periods with the sound-off and sound-on, there was a significant reduction ($Chi^2 = 42.1$, df = 1, $p \leq 0.01$) in activity of 18.2% (Fig. 4). Grain consumption in the nonsound room increased from an average of 202 g to 273 g per inspection (35%) during this period.

To determine if decibel level influenced the rat activity within the sound room, the 64 food spots were divided for analysis into quadrants of 16 spots each (Fig. 1). Again, each period consisted of 5 inspections for a total of 80 observations per quadrant. There was no significant difference ($Chi^2 = 6.9$ and 9.8, df = 3, $p > 0.01$) during either replication in activity between the sound level quadrants (Table 2).

In the second replication, overall change in sound-on activity, although significant ($Chi^2 = 16.5$, df = 1, $p \leq 0.01$), was only 5.6%. Grain consumption in the nonsound room decreased from 191 g to 110 g per station (42% during the sound-on period, however this change was not significant ($p > 0.05$). During this period there was little variation in the number of visits recorded per inspection, but they appeared to vary

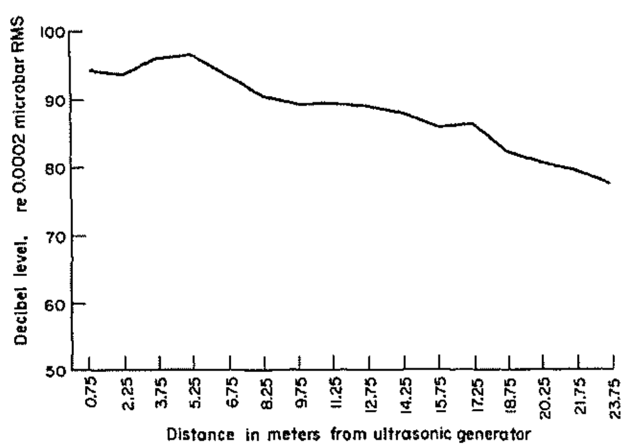

FIG. 3. Sound gradient produced by a type E generator over the food spot area.

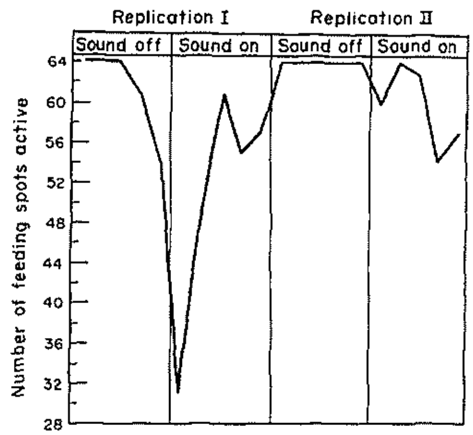

FIG. 4. Feeding spots visited during five observations per 3-week period.

TABLE 2. SUMMARY OF FEEDING SPOT ACTIVITY BY QUADRANT (16 SPOTS EACH) PER PERIOD (GENERATOR E)

Quadrant* and decibel levels	Total number of feeding spots active					
	Sound off	Sound on	Percent change	Sound off	Sound on	Percent change
	Replication 1			Replication 2		
A—92.5–102.5	80	68	15.0	80	70	12.5
B—87.5–95.5	80	65	18.7	80	76	5.0
C—83.5–91.0	79	55	30.4	80	79	1.3
D—75.5–83.5	68	63	7.4	80	77	3.8
Total	307	252	$\bar{X} = 18.2$	320	302	$\bar{X} = 5.6$

* Quadrant A closest to ultrasonic generator.

according to the sound level pressure. In quadrant A, with sound levels between 92.5–102.5 db, the percent activity change was greater than twice that of any other quadrant.

DISCUSSION

The significant increase of grain consumption in the nonsound room during the operation of type C generators was the only suggestion that type C devices had any measurable influence on rat activity. Possibly these units were sufficiently aversive to cause rats to spend less time in the sound field but not noxious enough to exclude them from food sources within it. Our findings with the type C generator agreed with those of GREAVES and ROWE (1969); and BURGER (1967)—high frequency sound and ultrasound were not repellent enough to keep rats from food and water.

A similar increase of grain consumption in the nonsound room occurred during the first replication with the type E generator. In addition, there was significant decrease in activity within the sound room at least during the first week of operation. A significant decrease ($p \leq 0.01$) in the ratio of no visits to visits during the sound-on period indicates that the animals were becoming habituated to the sound by the 2nd week. Habituation was further demonstrated by increased activity within the sound room and decreased grain consumption in the nonsound room during the second replication.

Thus, our studies did not demonstrate that either type of ultrasonic generator would be effective in expelling Norway rats from warehouses or preventing them from taking food, even quite close to the sound source.

Acknowledgements—We wish to thank GEORGE CORNER and the other personnel of the Denver Wildlife Research Center's Bioelectronic unit for assistance in this work. This study was in part funded by Pioneering Research Laboratory, U.S. Army Natick Laboratories, Natick, Massachusetts 01760.

REFERENCES

BELLUZZI, J. D. and GROSSMAN, S. P. (1969) Avoidance learning motivated by high-frequency sound and electric shock. *Physiol. Behav.* **4**, 371–73.

BURGER, R. E. (1967) Responses of rodents to high frequency sound. M.A. Thesis. Bowling Green State Univ., Bowling Green, Ohio.

CAMPBELL, B. A. and BLOOM, J. M. (1965) Relative aversiveness of noise and shock. *J. comp. Psychol.* **60**, 440–42.

GOUREVITCH, G. and HACK, M. H. (1966) Audibility in the rat. *J. comp. physiol. Psychol.* **62**, 289–91.

GREAVES, J. H. and ROWE, F. P. (1969) Responses of confined rodent populations to an ultrasonic generator. *J. Wildl. Mgmt* **33**, 409–17.

KENT, E. and GROSSMAN, S. P. (1968) An ultrasonic UCS. *Physiol. Behav.* **3**, 361–62.

MARSH, B. T., JACKSON, W. B. and BECK, J. R. (1962) Use of ultrasonics in elevator rat control. *Grain Age* **3**, 27–31.

MYERS, A. K. (1967) Contradictory evidence for aversion to auditory stimuli resulting from different test methods. *J. comp. physiol. Psychol.* **64**, 171–75.

SPROCK, C. M., HOWARD, W. E. and JACOB, F. C. (1967) Sounds as a deterrent to rats and mice. *J. Wildl. Mgmt* **31**, 729–41.